



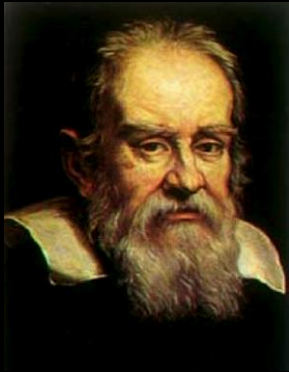
Revealing Europa's Ocean

Robert T. Pappalardo

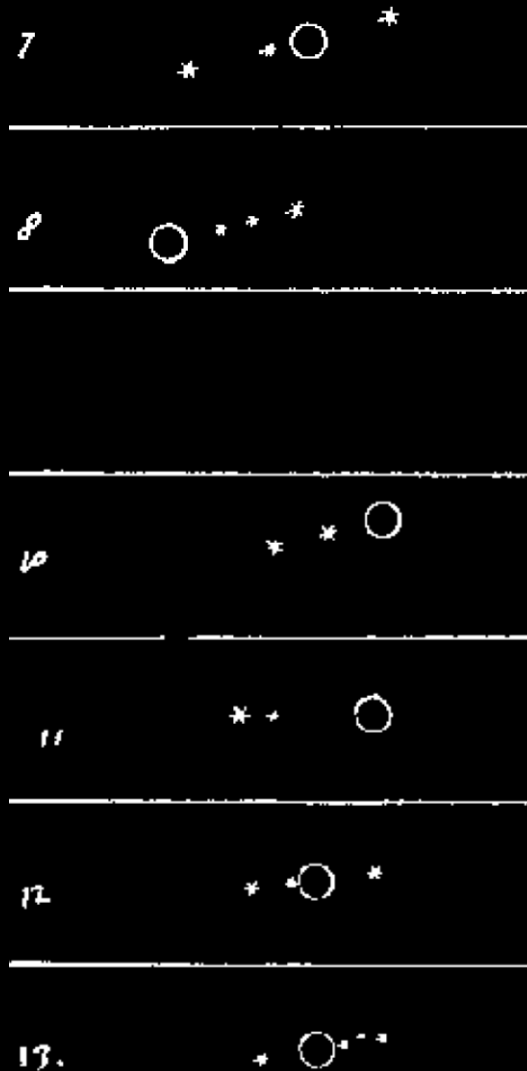
*Jet Propulsion Laboratory
California Institute of Technology*

Mosaic by Ted Stryk

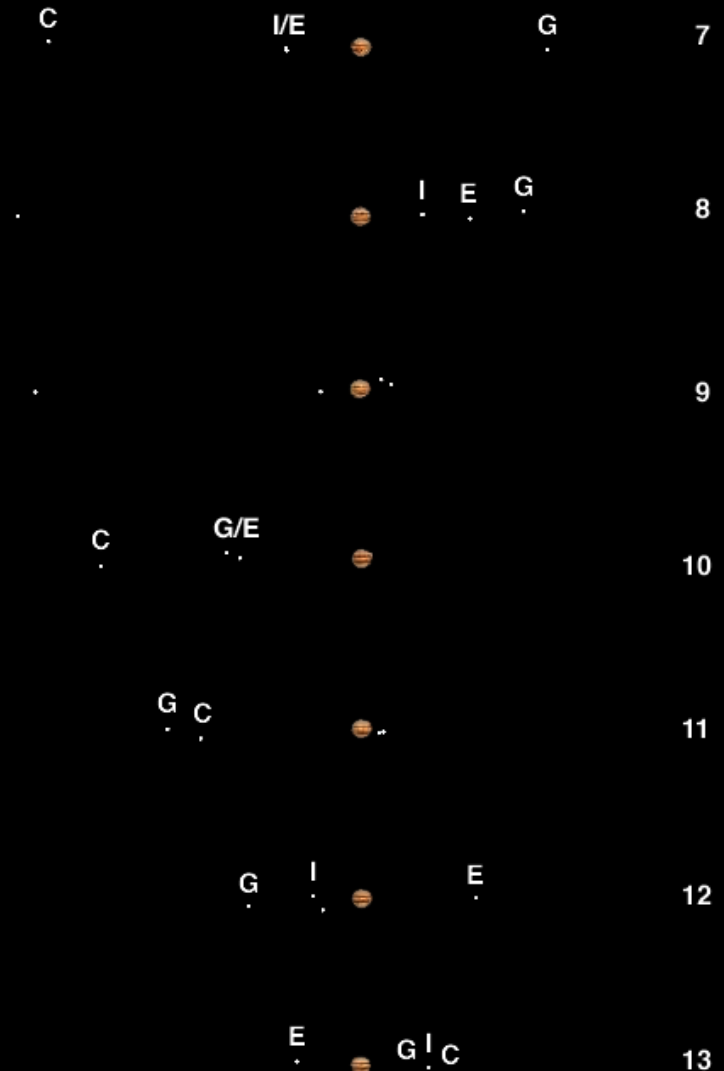
The Galilean Satellites: January 1610



Galileo's sketches

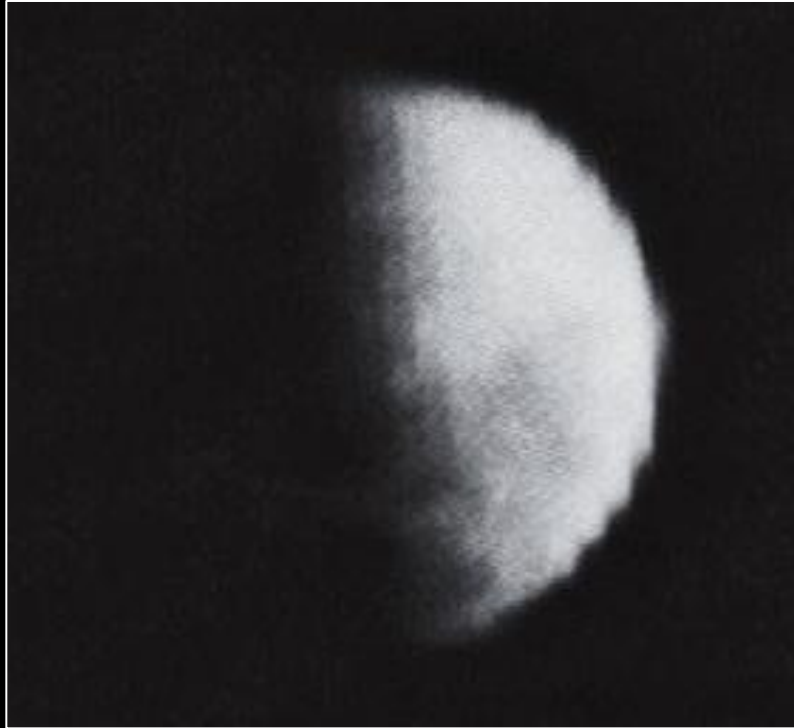


JPL Solar System Simulator

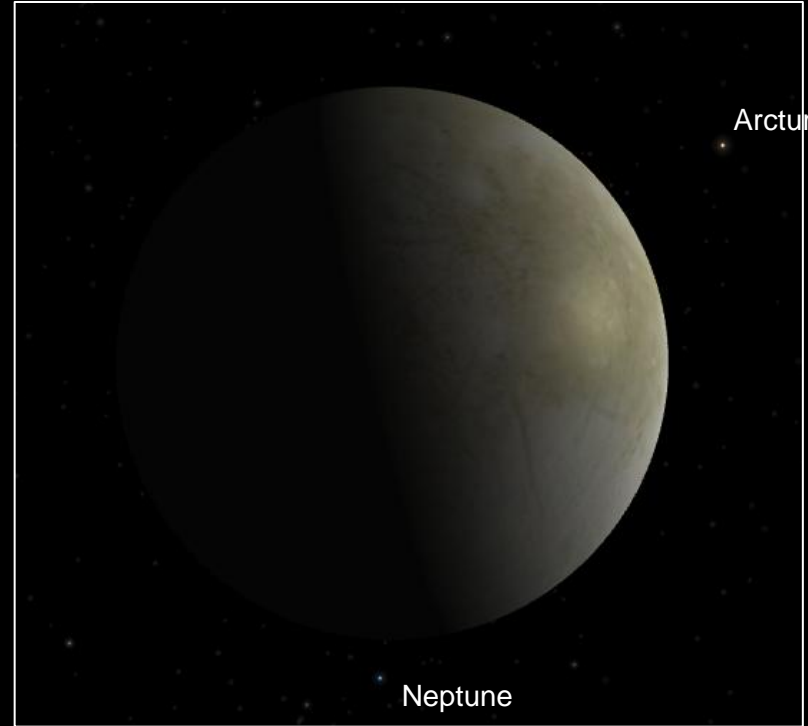




Pioneer 10 Views Europa (1973)



Pioneer 10

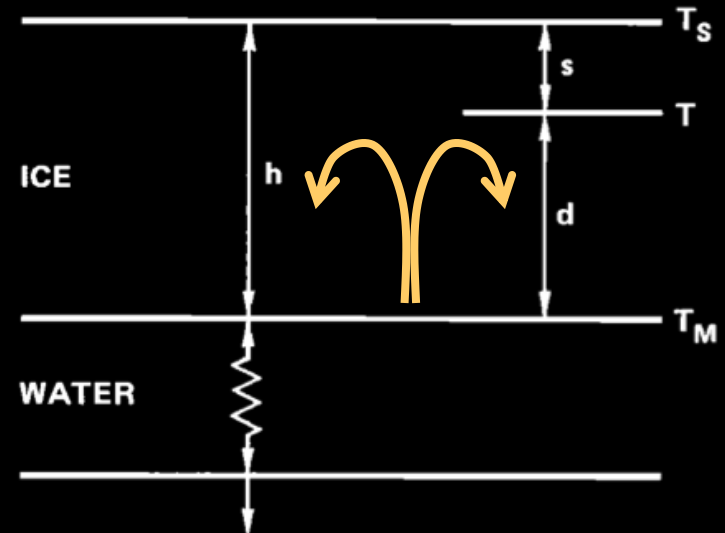
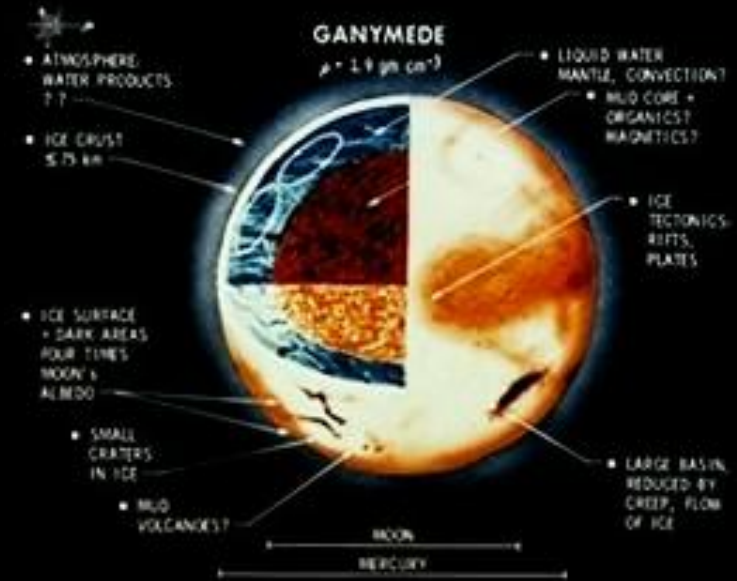


JPL Eyes on the Solar System

- Scan by imaging photopolarimeter
- Dec. 3, 1973, ~200 km/pixel

Oceans Come and Go, and Return Again

- 1971–1977: Early satellite oceans proposed from thermal-compositional models [*Lewis, Consolmagno, Fanale*]
- Late 1979–1983: Tidal heating might maintain oceans, but convection of overlying ice might freeze oceans [*Cassen, Peale, Reynolds, Squyres*]
- 1989: Tidal heating of Europa's ice could be sufficient to maintain a conductive ice shell above a global ocean [*Ojakangas & Stevenson*]

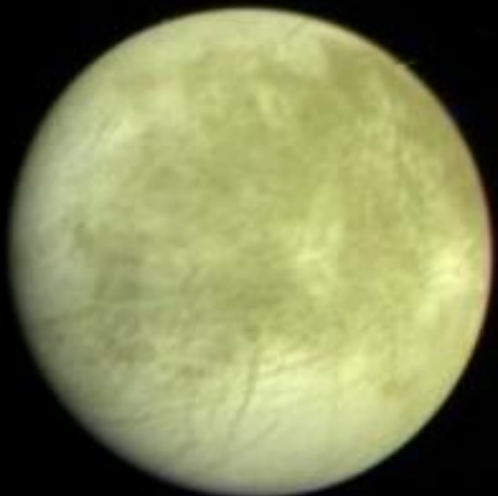


[*Reynolds & Cassen., 1979*]

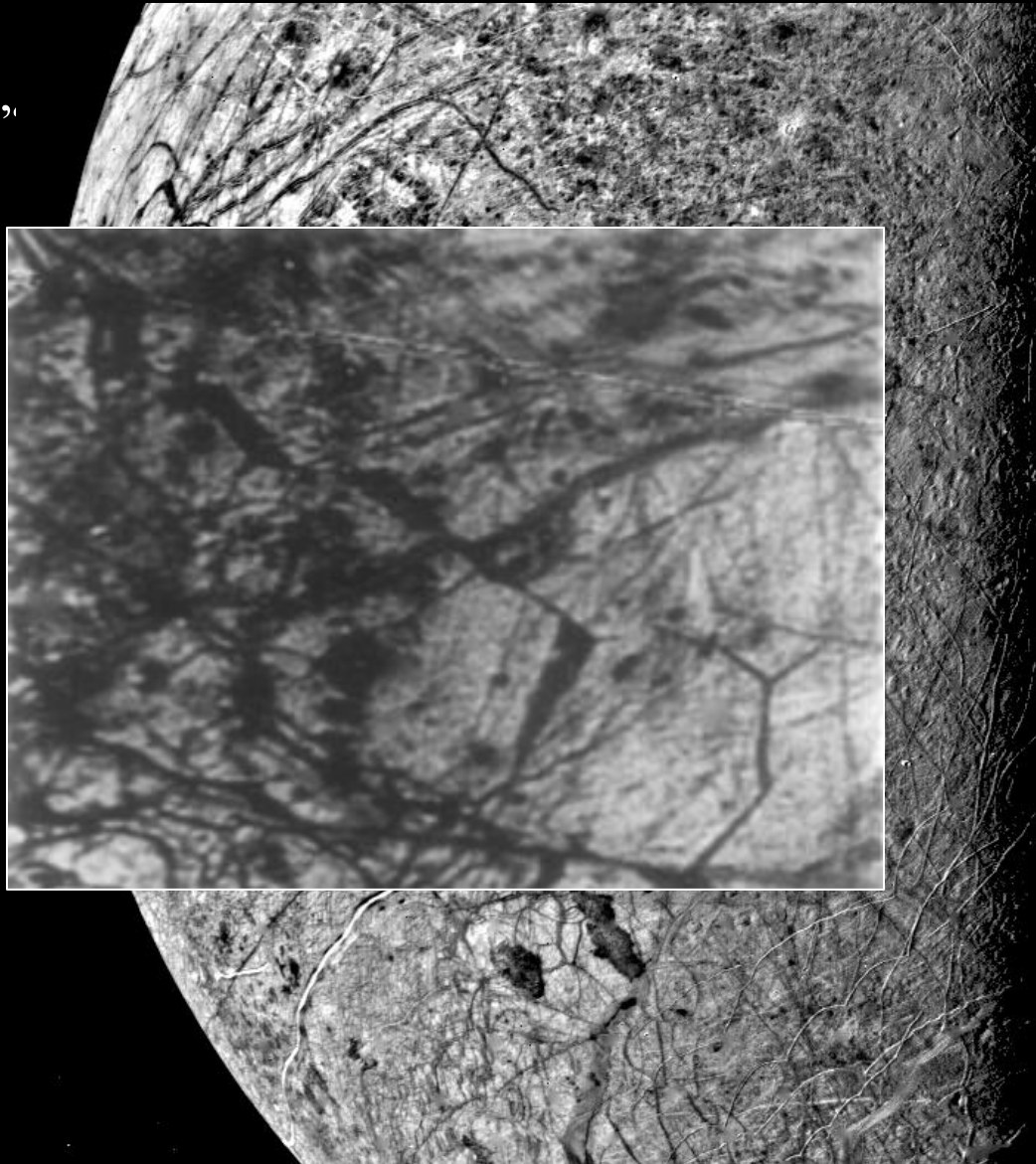
Voyagers View Europa (1979)

- Few large impact craters
 - young surface or “relaxation”
- Mottled terrain
 - internal activity or only impacts?
- Bright, lineated plains
 - crustal mobility

[*Schenk & Seyfert, 1980;*
Schenk & McKinnon, 1989]



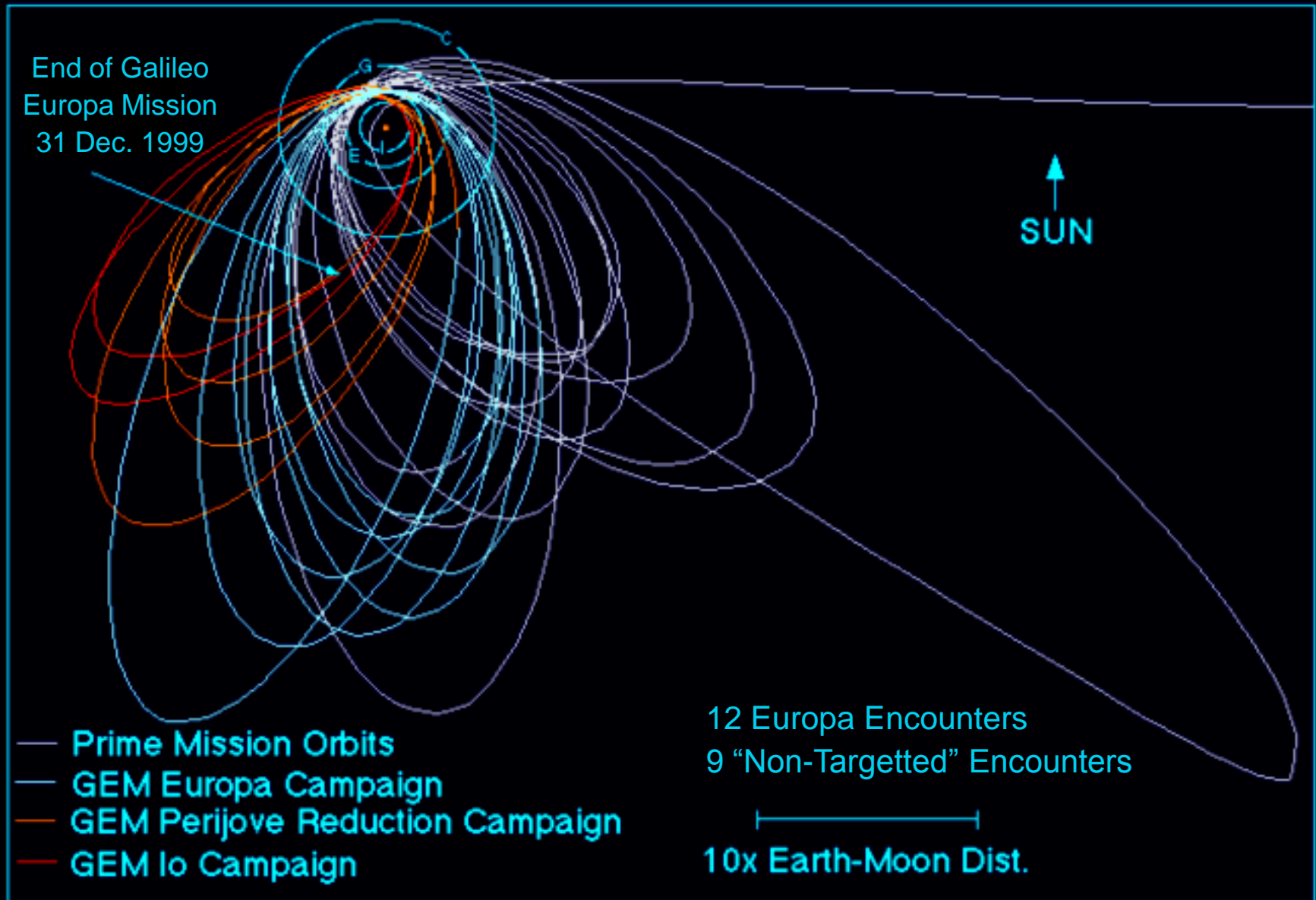
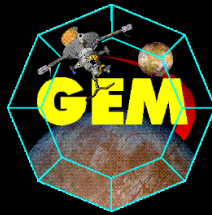
Voyager 1 (20 km/pixel)



Voyager 2 (2 km/pixel)



Galileo Orbital Tour (1996-1999)



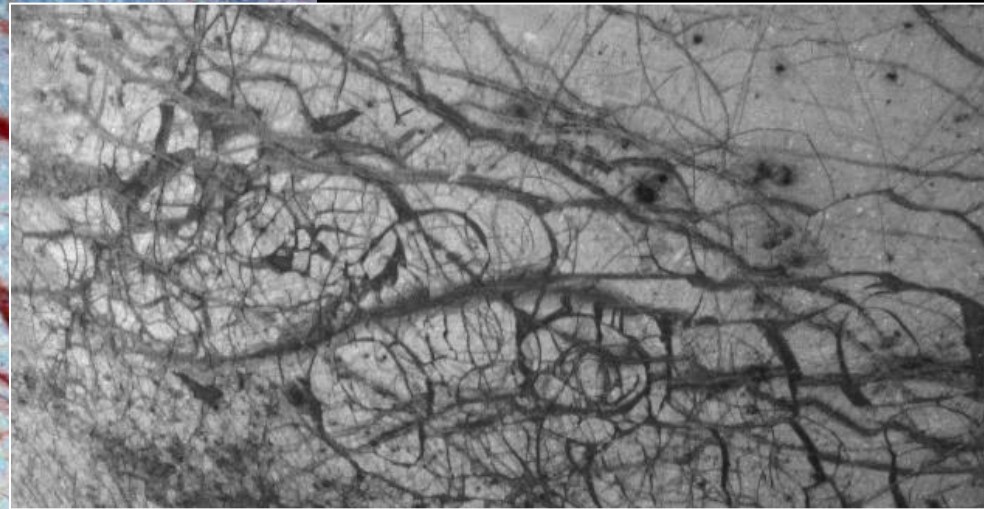
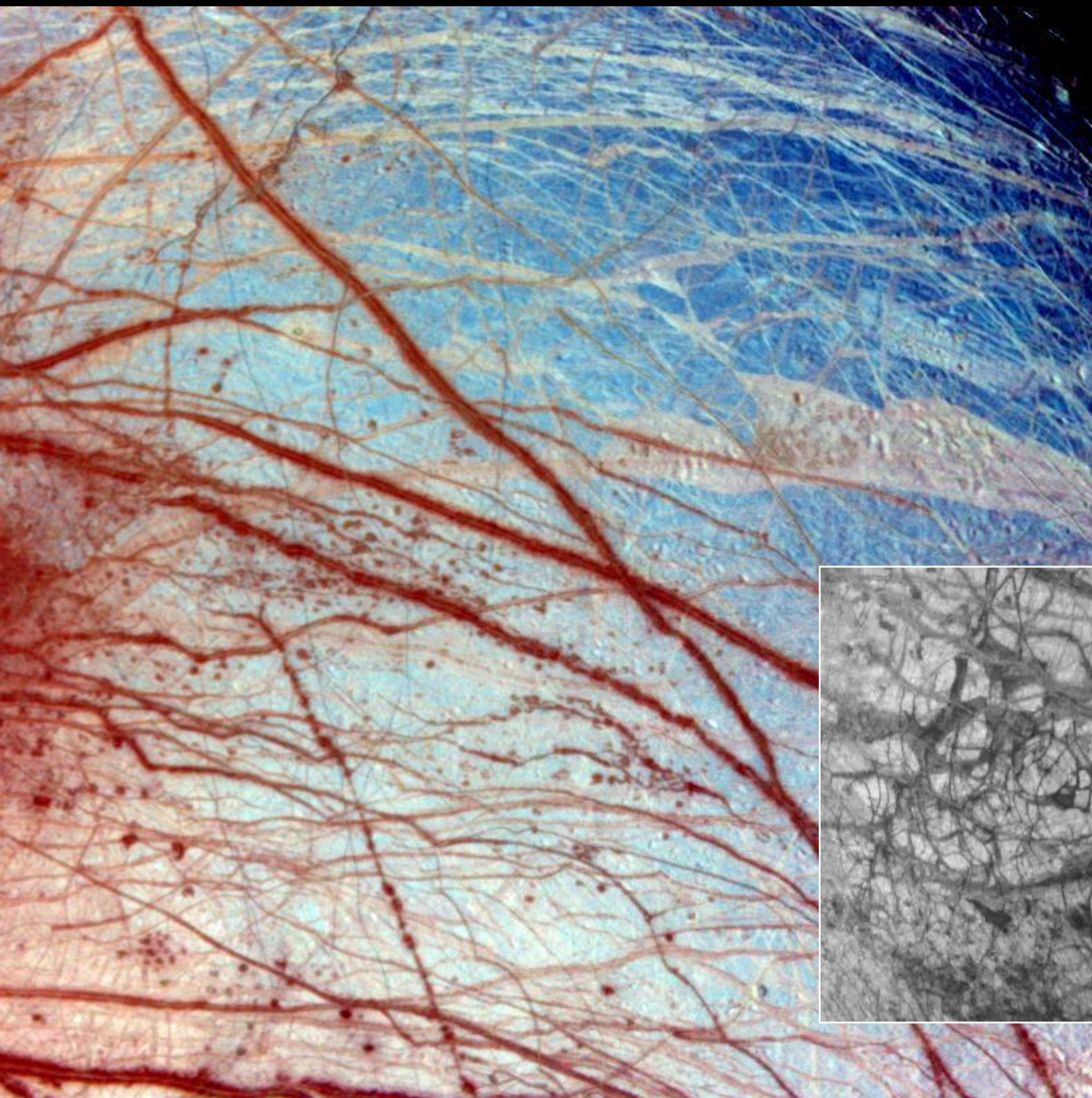


Galileo Imaging Team (1996)

Galileo's First Views of Europa (1996)

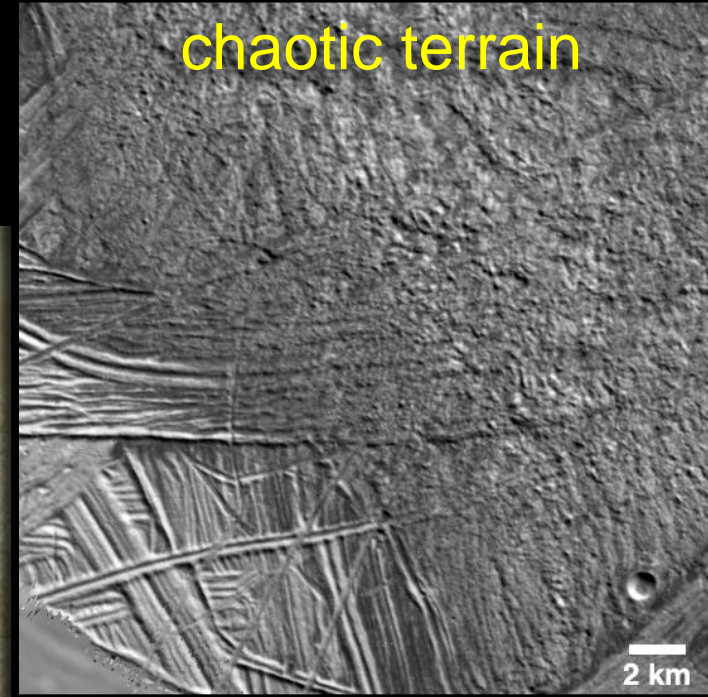
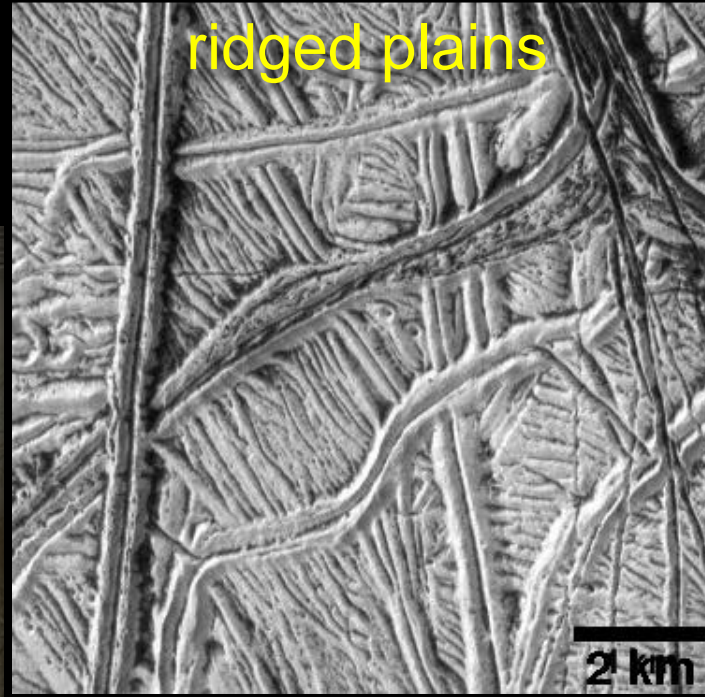
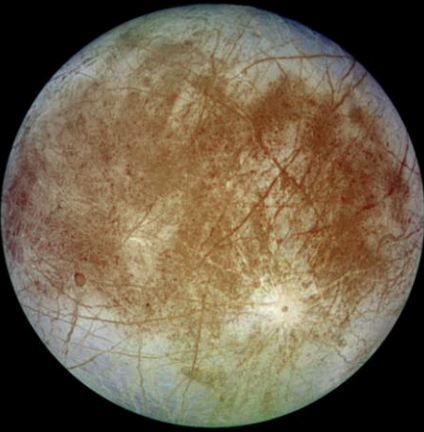


- Pits (endogenic?)
- Spots (volcanic?)
- Age brightening
- Nonsynchronous rotation
- Crustal mobility

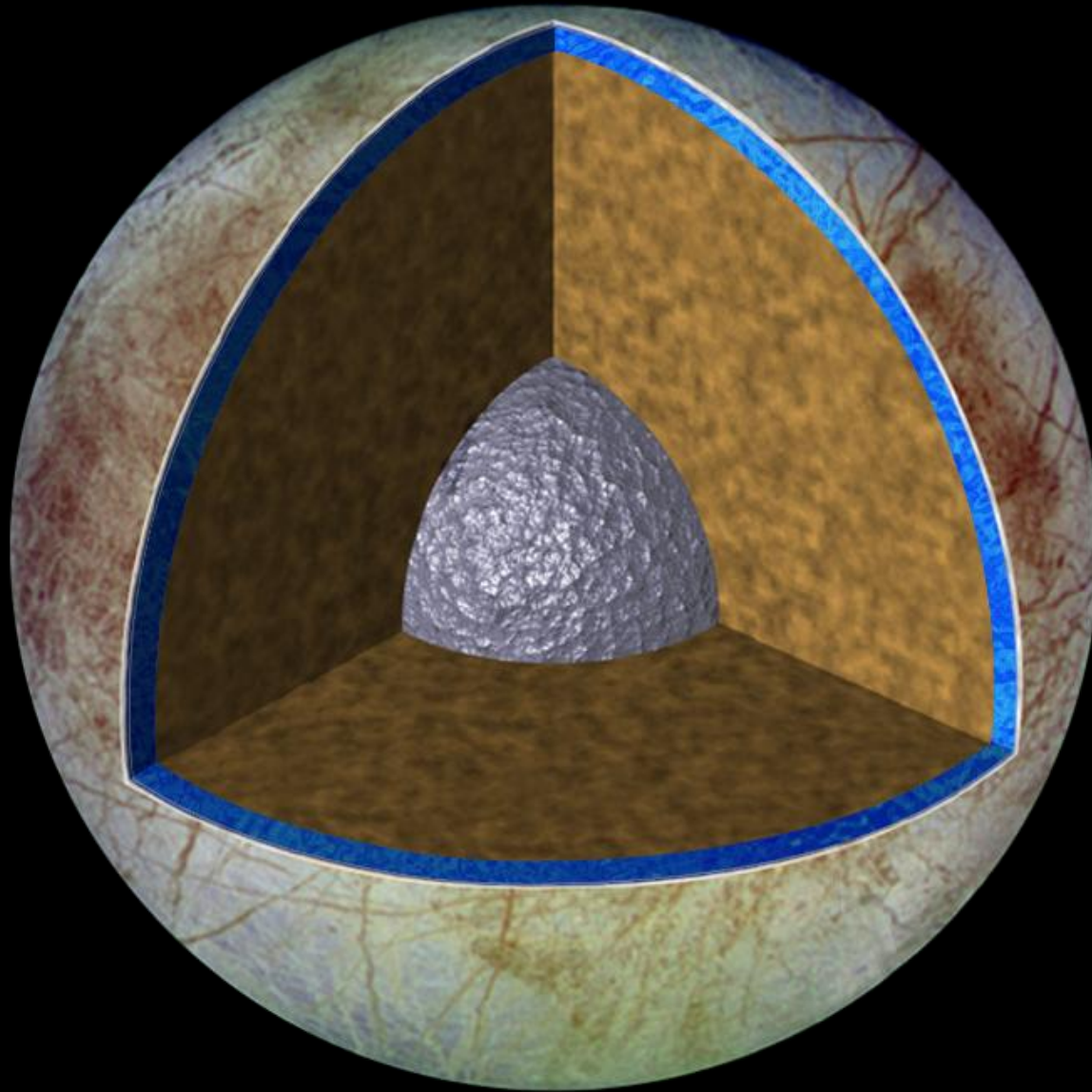


Color composite by Paul Geissler

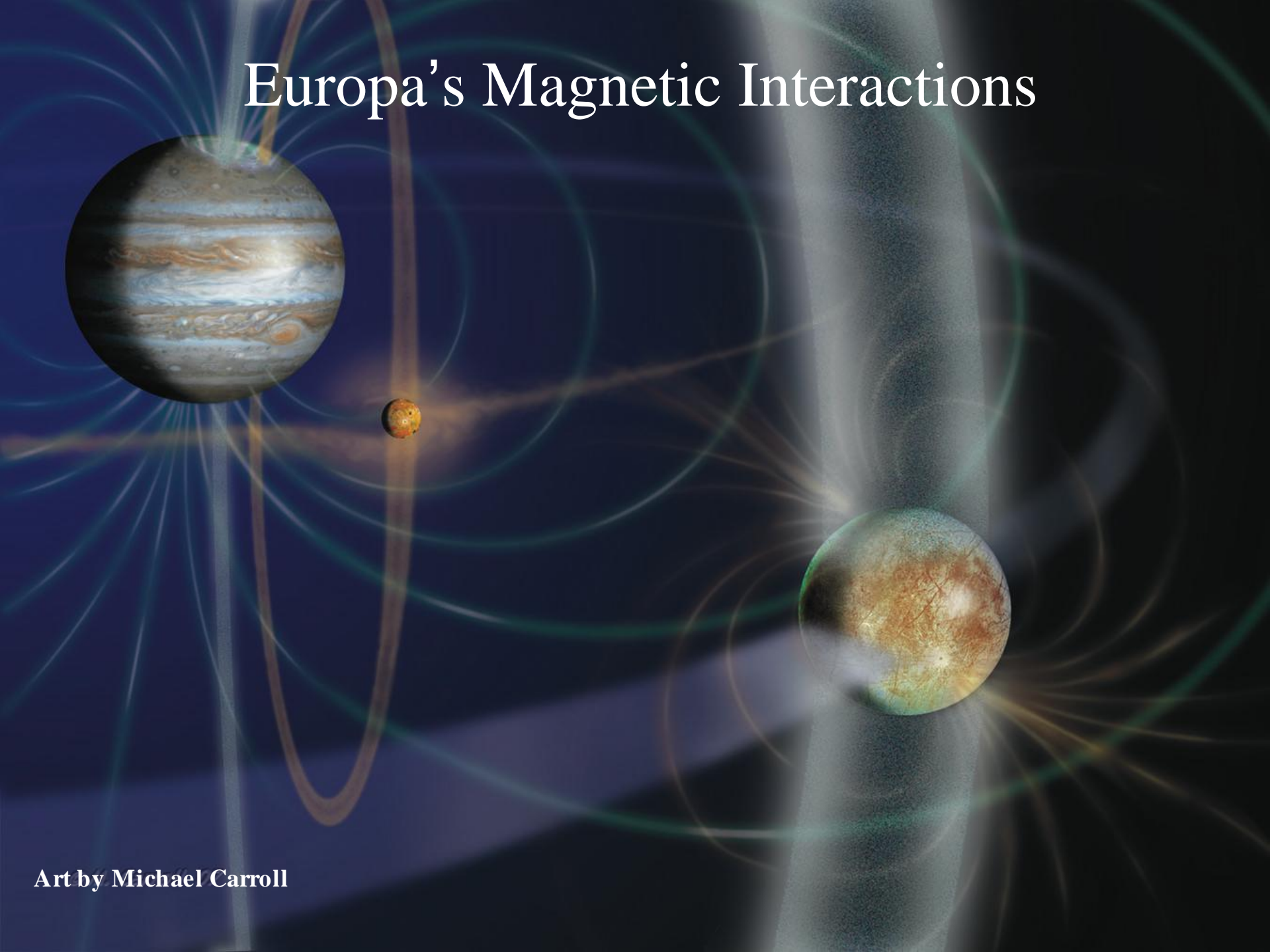
Europa's Surface



Europa's Interior



Europa's Magnetic Interactions

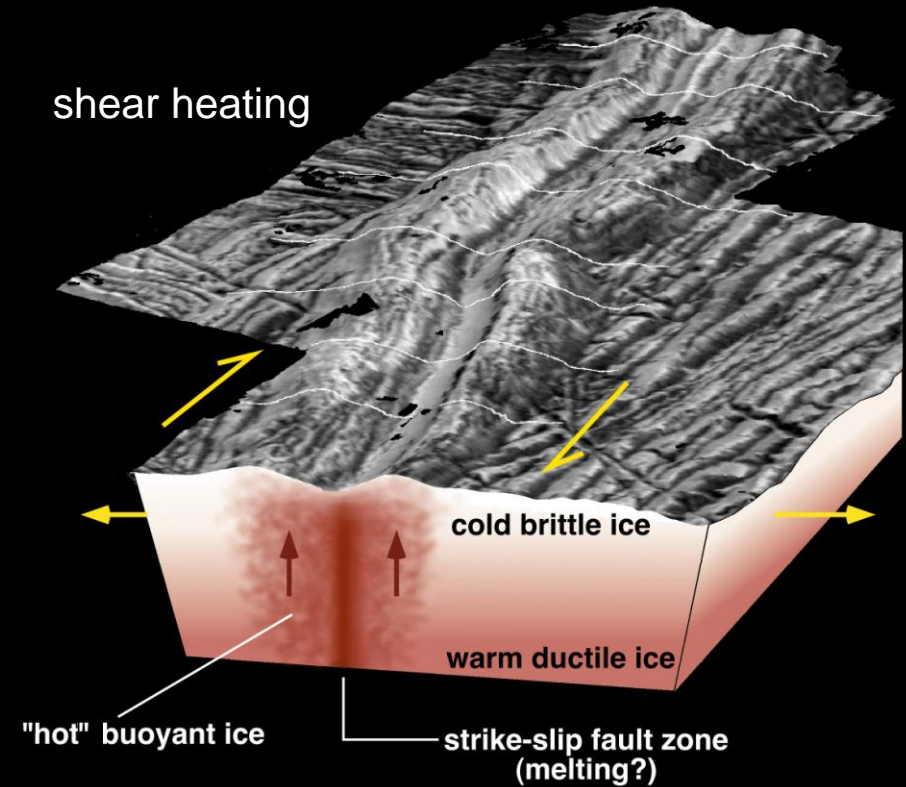


Art by Michael Carroll

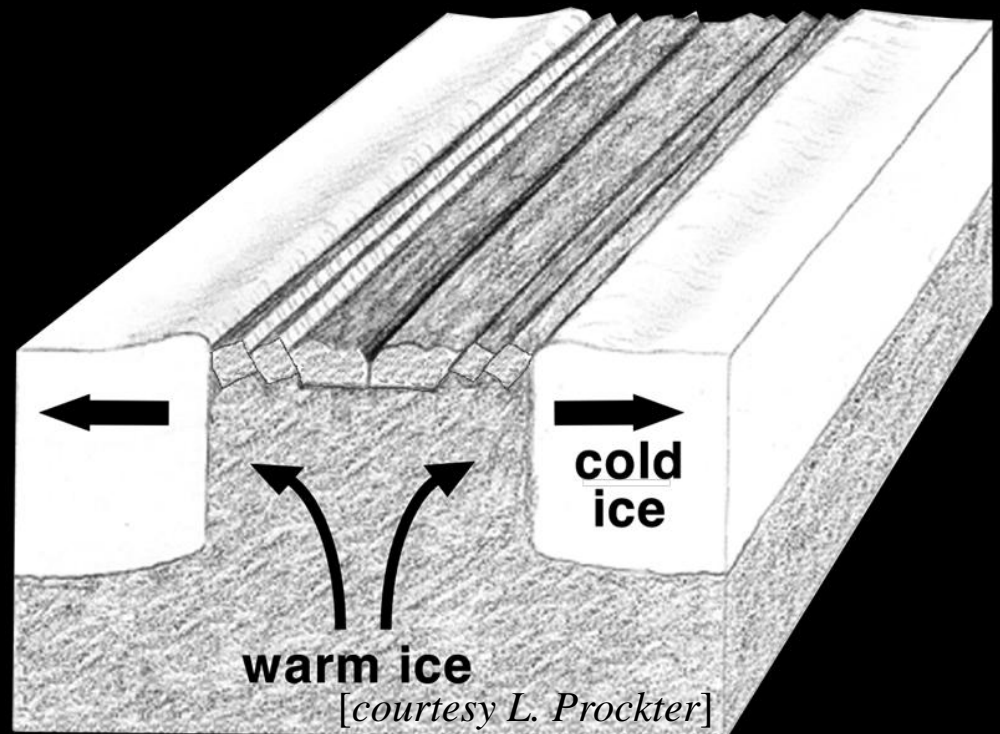
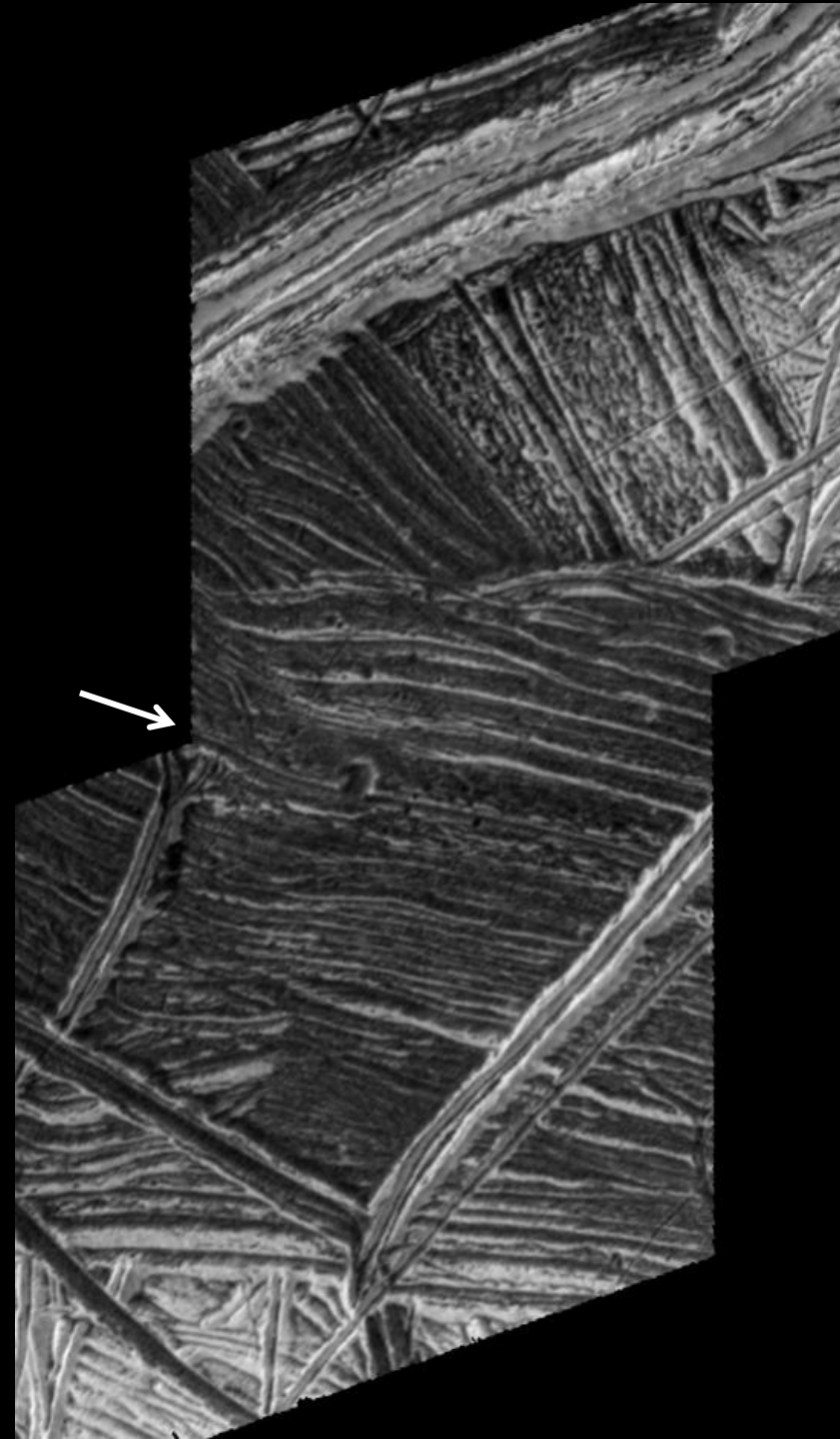
Ridges



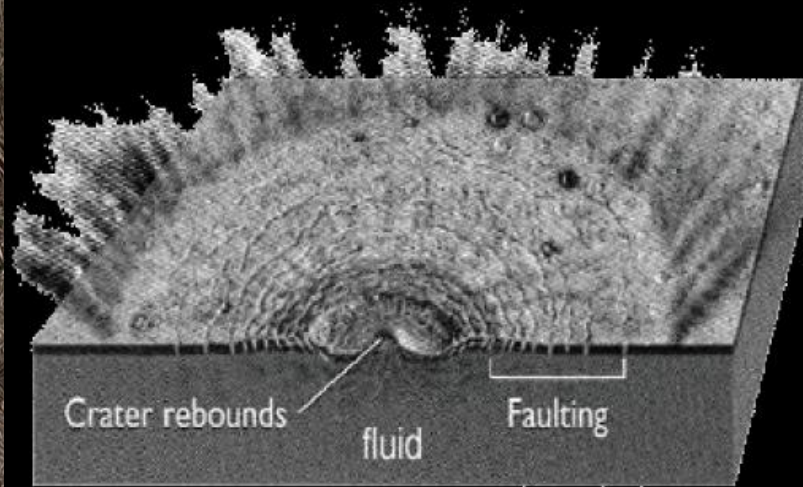
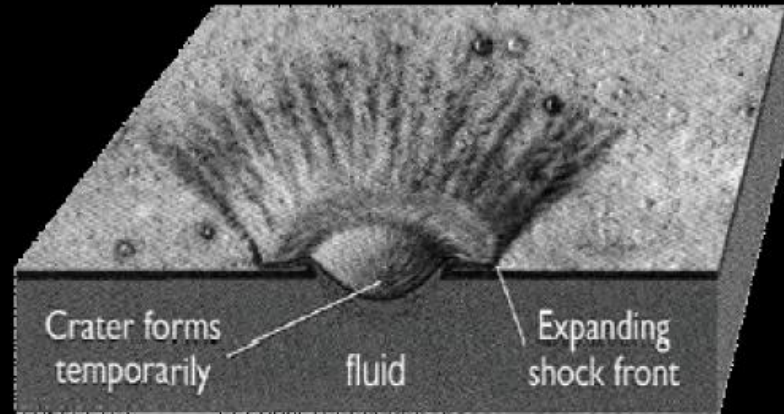
Ridge Formation Models



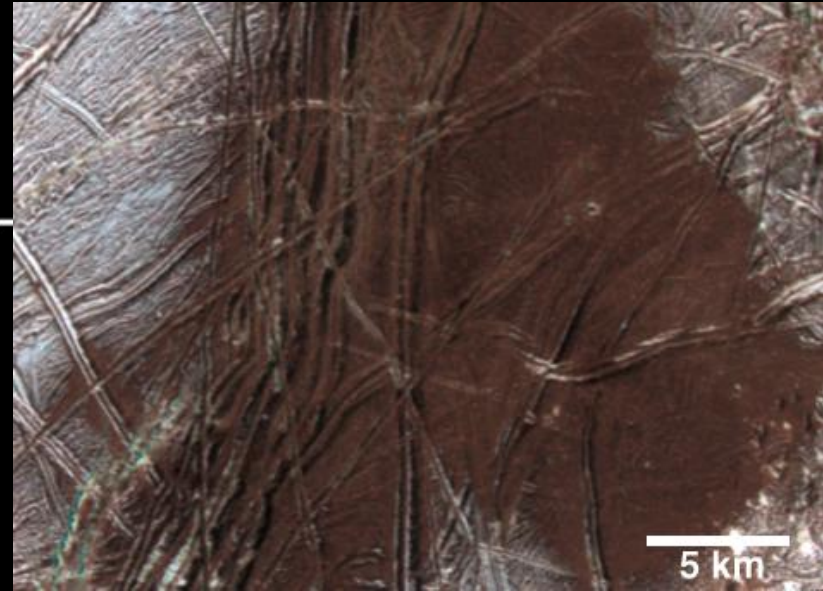
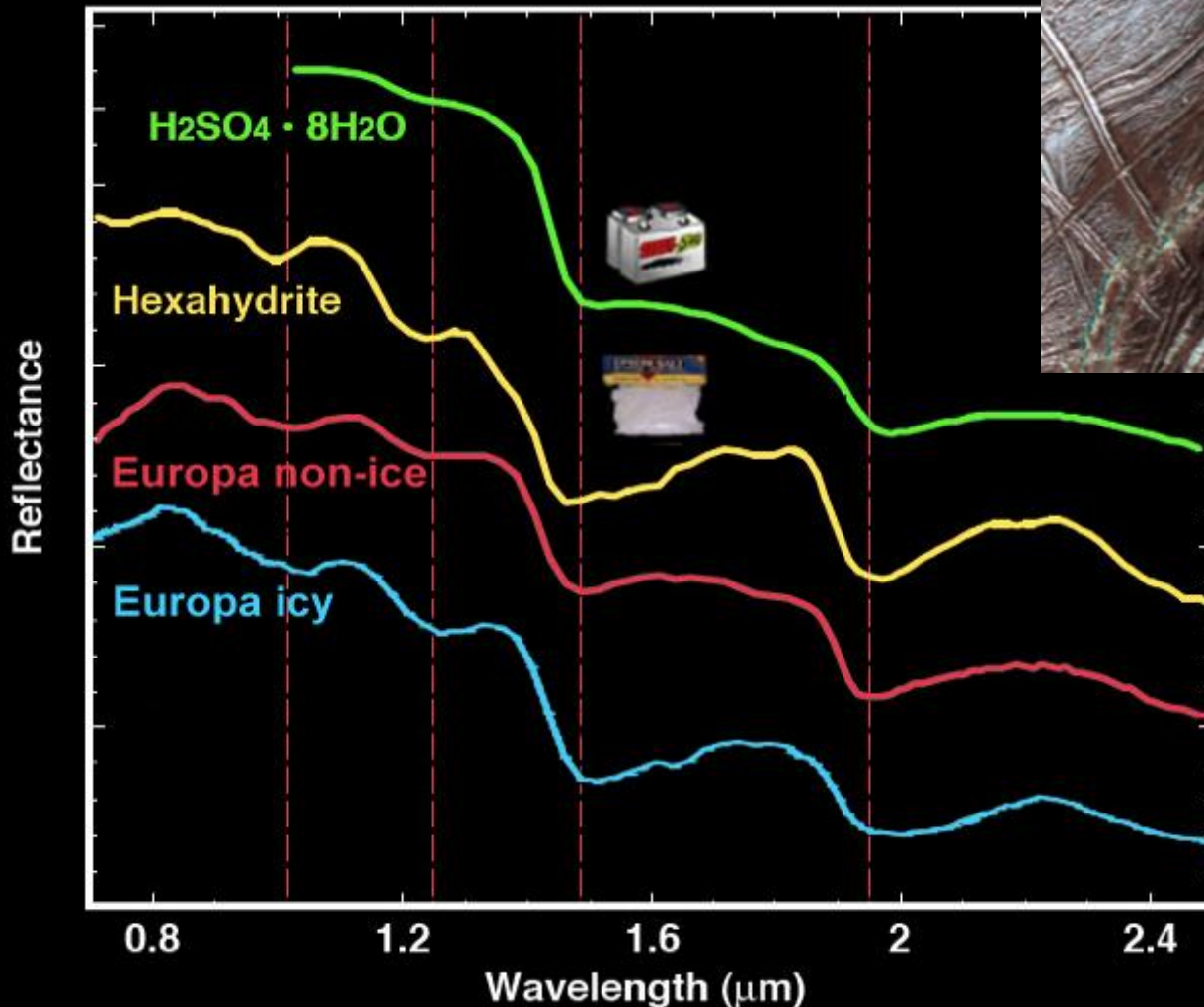
Bands



Impacts



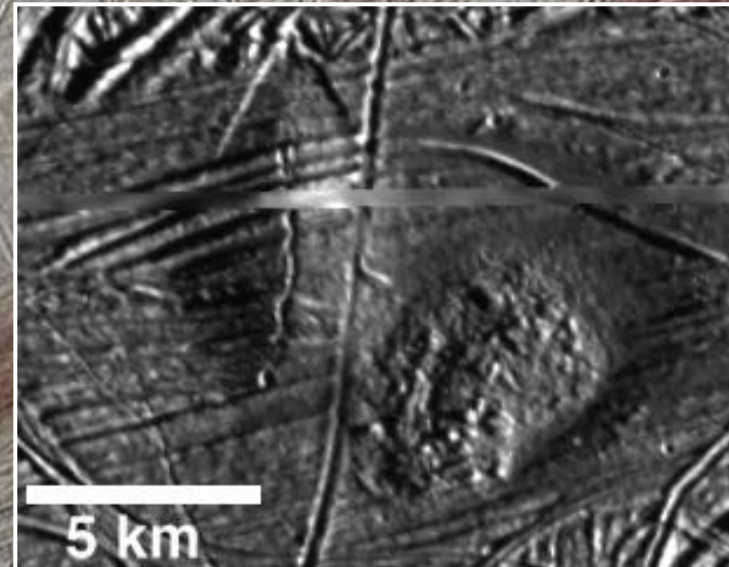
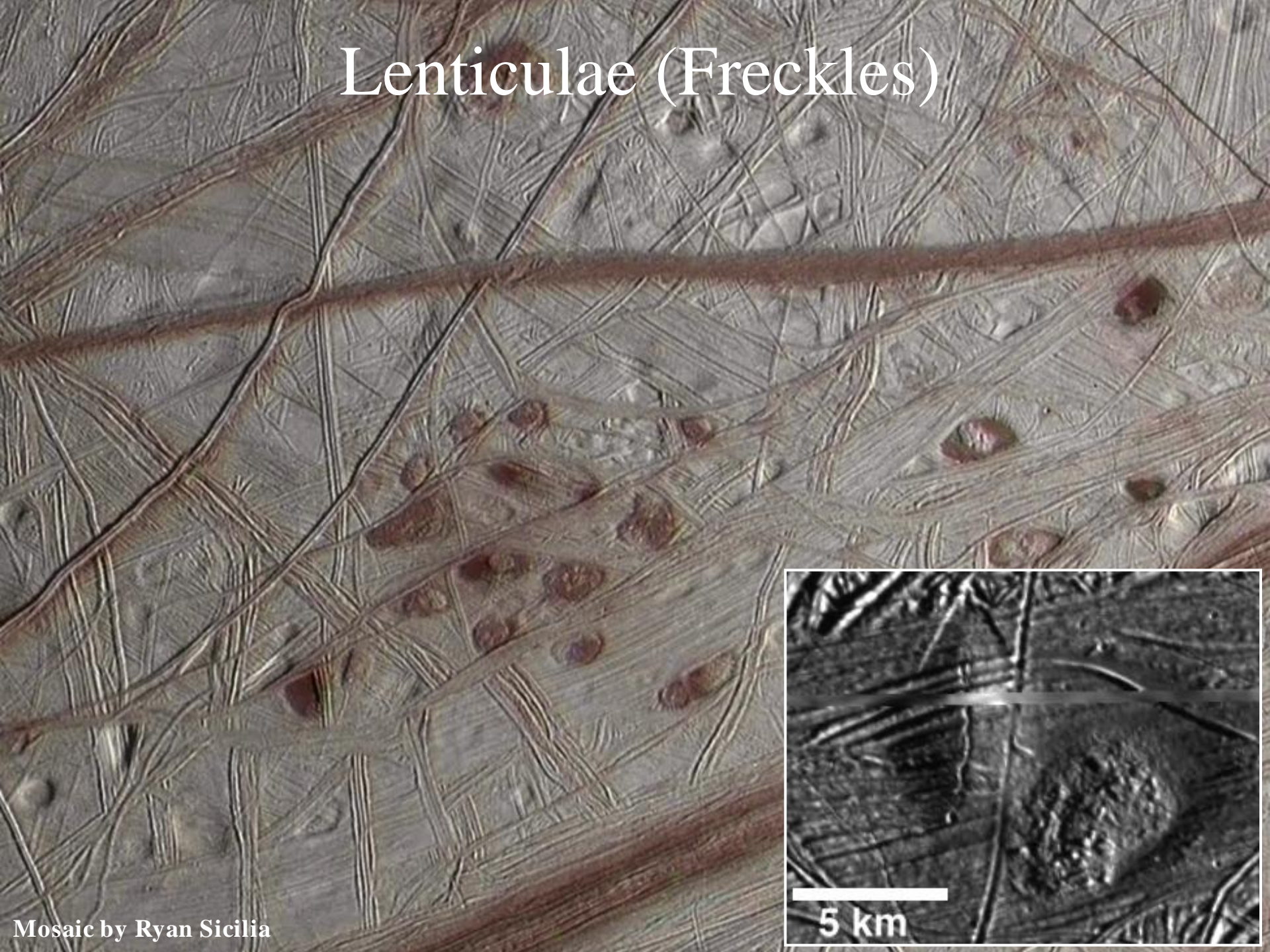
Surface Composition



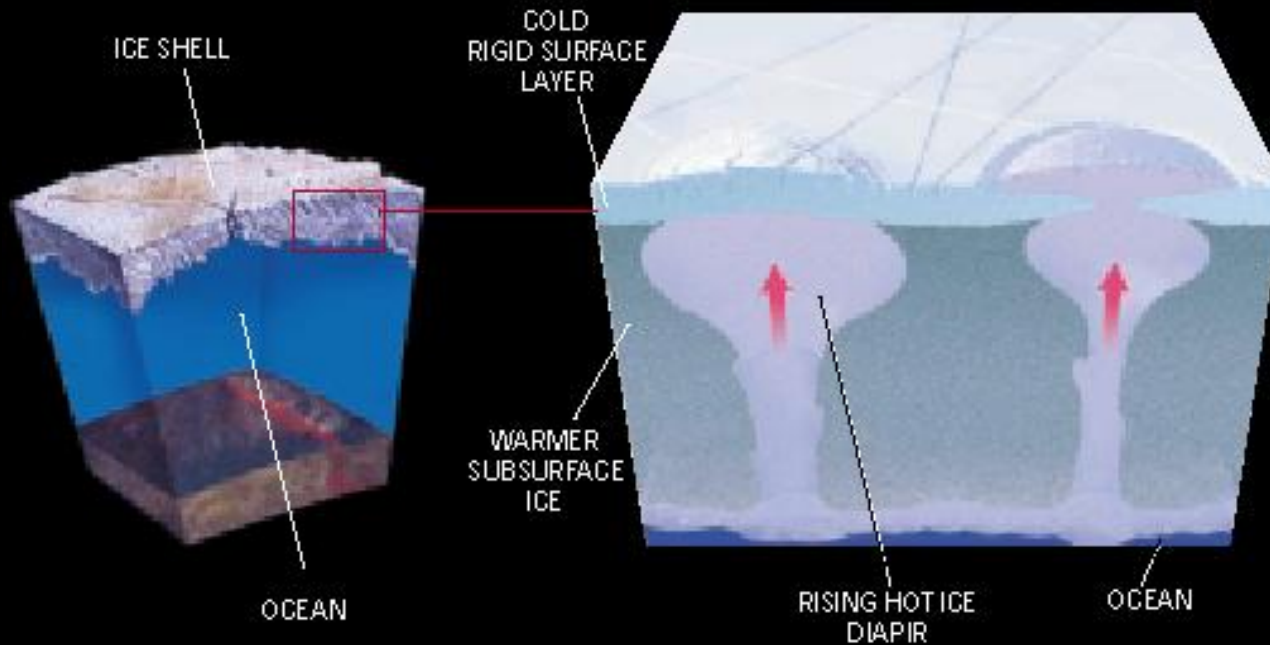
Non-ice candidates:

- Sulfate salts
($\text{MgSO}_4 \cdot n\text{H}_2\text{O}$)
- Sulfuric acid
($\text{H}_2\text{SO}_4 \cdot n\text{H}_2\text{O}$)

Lenticulae (Freckles)



Icy Lava Lamp?



$T = 100\text{ K}$

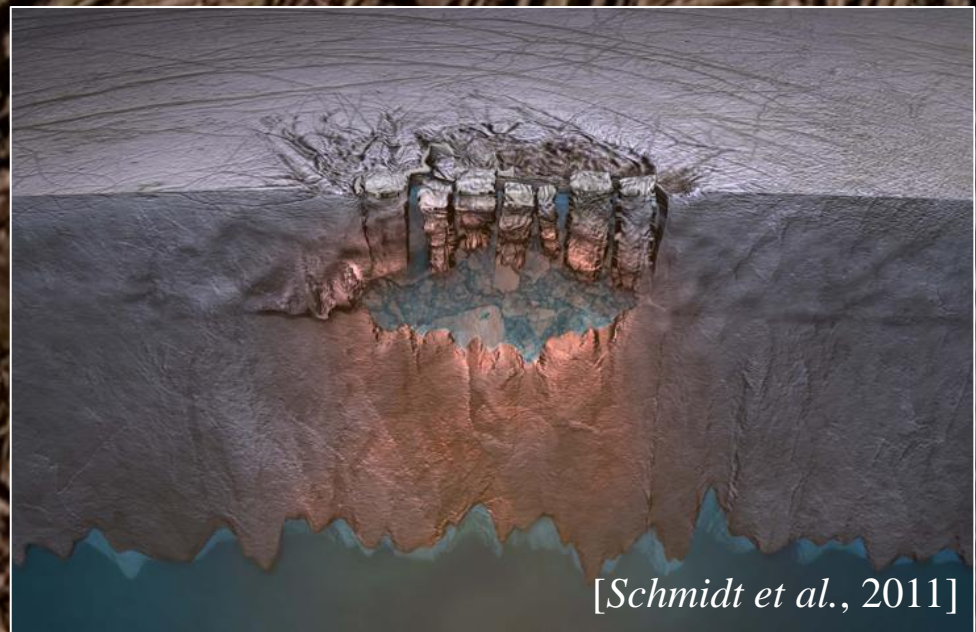
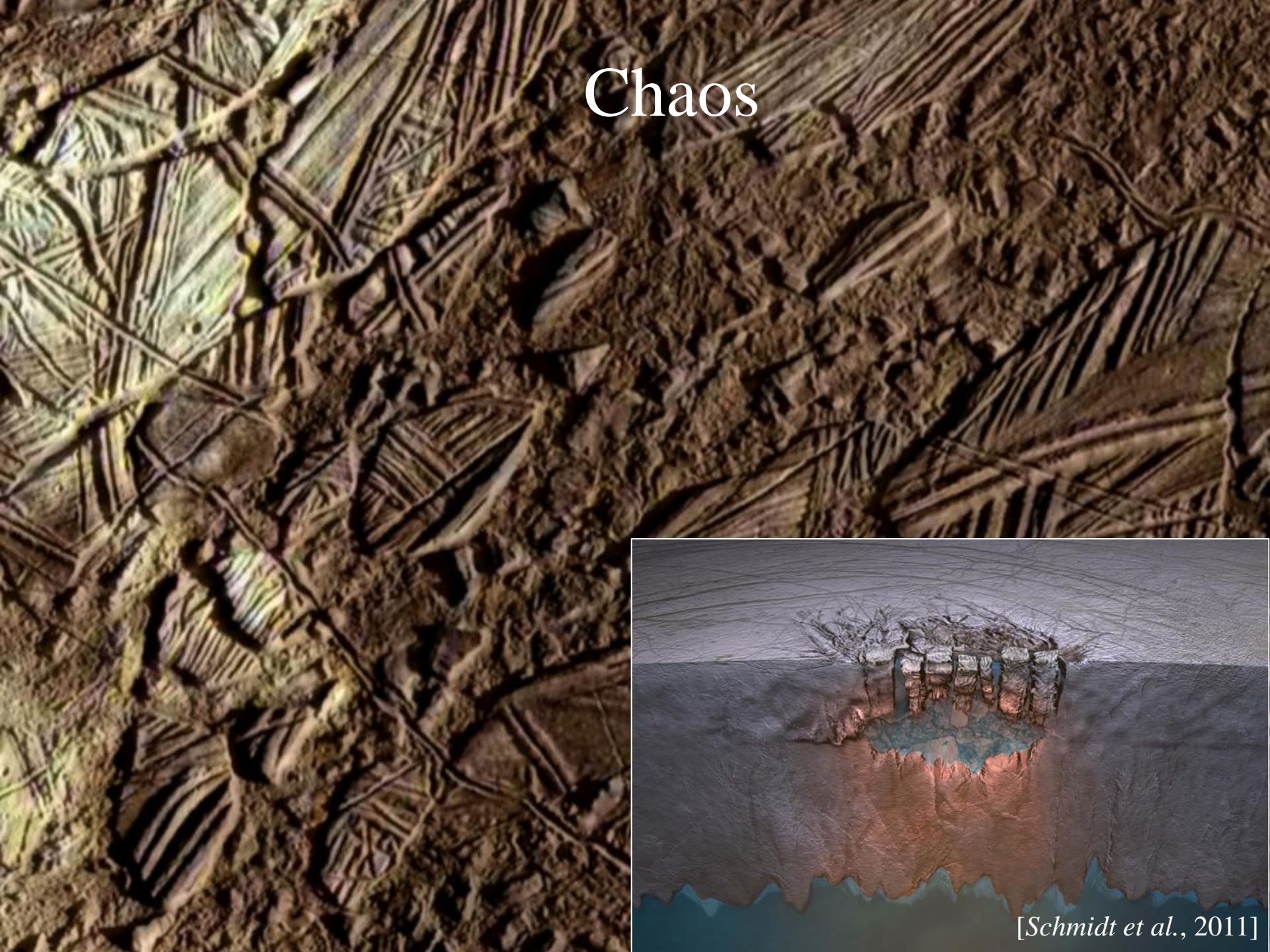
cold, stiff ice

warm, flowing ice

$T = 260\text{ K}$

[courtesy A. Barr]

Chaos



[Schmidt et al., 2011]

Icebergs?



270 m

Europa: Ingredients for Life?



Water: *More than 2x all of Earth's oceans*



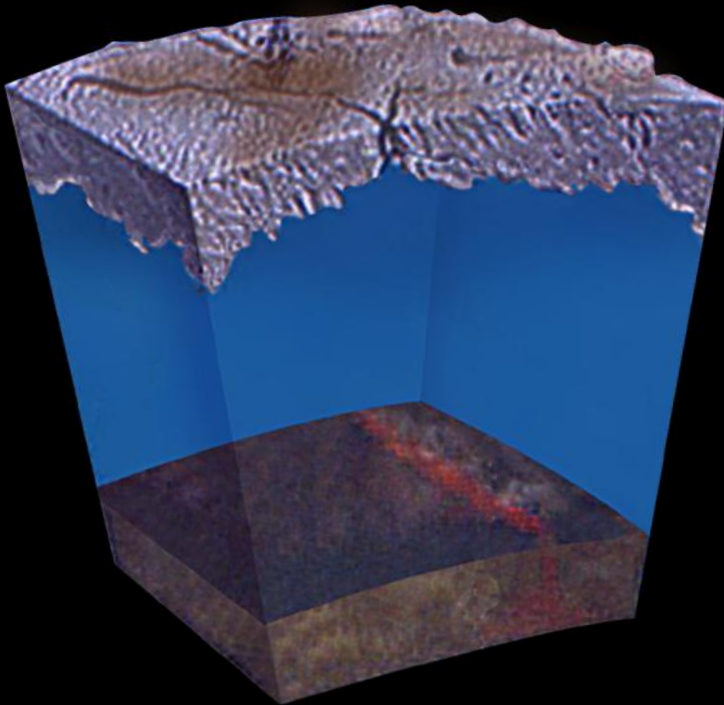
Essential elements: *From formation and impacts*



Chemical energy: *Potentially from above and below*



Stability: *Variable, but “simmering” for 4 billion years*



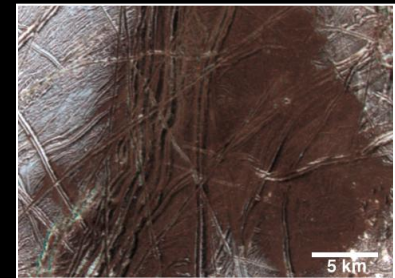
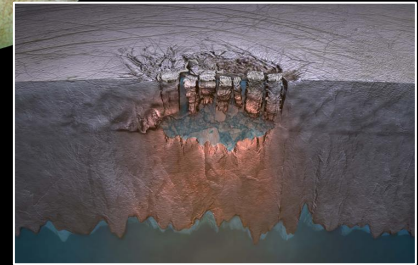
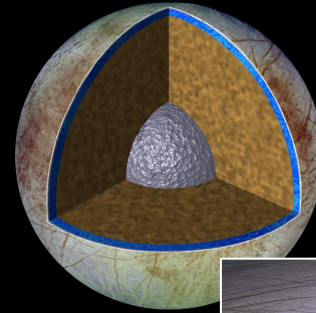
“Black smoker” on Earth's ocean floor

Woods Hole Oceanographic Institution



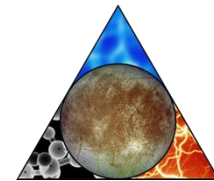
Understanding Europa's Habitability: Key Issues

- **Ocean:** Existence, extent, and salinity
- **Ice Shell:** Existence and nature of water within or beneath, and nature of surface-ice-ocean exchange
- **Composition:** Distribution and chemistry of key compounds and the links to ocean composition
- **Geology:** Characteristics and formation of surface features, including sites of recent or current activity





Looking Forward: Europa Clipper



Science:

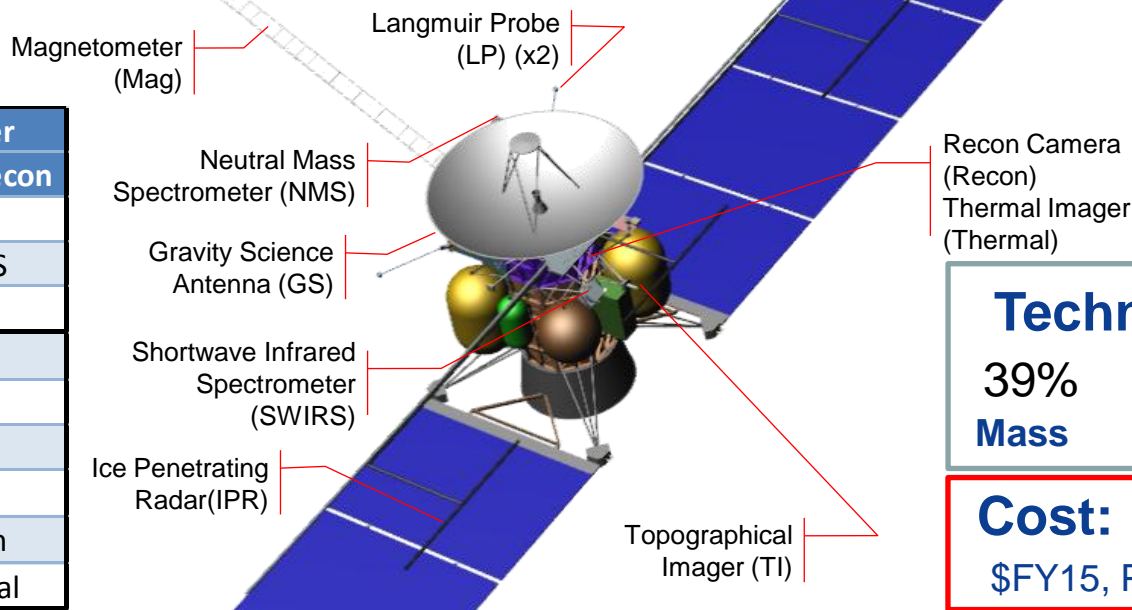
Objective	Clipper
	Enhanced w Recon
Ocean	✓
Ice Shell	✓
Composition	✓
Geology	✓
Recon	✓

Operations Concept:

- 32 low altitude flybys of Europa from Jupiter orbit over 2.3 years
- Detailed investigation of globally distributed regions of Europa
- Simple repetitive science operations
- Landing site reconnaissance capability

Payload:

Instrument	Clipper
	Enh w Recon
Floor	IPR
	SWIRS
	TI
Baseline	NMS
	MAG
	LP
	GS
	Recon
	Thermal



Technical Margins

39%	40%	75%
Mass	Power	Data

Cost: \$2.0B
\$FY15, Phases A-E Excl LV

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